

Determination of the Geoid Heights of Awka and Environ from the Satellite Altimetry data using Broadview RADAR Altimeter Toolbox (BRAT) and Sentinel-3 Missions

Godwin-Nwankwo O. L.¹, Ono M. N.², Eteje S. O.³

^{1,2}Department of Surveying and Geoinformatics, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria

³Department of Surveying and Geoinformatics, Dennis Osadebay University, Asaba, Delta State, Nigeria

ABSTRACT: Satellite altimetry has revolutionized our ability to measure Earth's surface with unprecedented accuracy, offering invaluable insights into various geophysical phenomena. This study presents the determination of geoid heights (Ns) of Awka and Environ utilizing the Broadview RADAR Altimeter Toolbox (BRAT) in conjunction with data from the Sentinel-3 missions. The geoid, a surface of constant gravitational potential representing mean sea level, is a fundamental reference surface for geodetic measurements and understanding Earth's gravity field. The methodology involves processing raw altimetry data acquired by the Sentinel-3 missions using BRAT, followed by precise corrections for various factors affecting the altimeter measurements, such as atmospheric delays, sea state bias, and orbit errors. Subsequently, the derived SSH data are combined with precise geoid models to compute the geoid heights at different spatial resolutions. The results demonstrate the effectiveness of the approach in determining geoid height (N) with high precision and spatial resolution, offering valuable contributions to geodetic research and applications. The utilization of Sentinel-3 data combined with BRAT facilitates robust and accurate geoid determination, which is essential for a wide range of geospatial applications, including oceanography, geophysics, and climate studies. The integration of BRAT and Sentinel-3 missions offers a powerful tool for geodetic research and applications, contributing to our understanding of Earth's dynamic processes and improving the accuracy of geospatial measurements.

KEYWORDS: Geoid Height, Satellite Altimetry, BRAT (Broadview RADAR Altimeter Toolbox), Sentinel-3 Missions

I. INTRODUCTION

The geoid is a theoretical surface that represents the shape of the Earth in the absence of topographic and oceanic features and is important for various applications, including oceanography, navigation, and mapping [1]. According to Flechtner *et al.* [2], the geoid height represents the deviation of the Earth's surface from a perfect ellipsoid and is used to determine the Earth's shape. The geometric height is also used to correct satellite altimetry measurements, ensuring that they accurately reflect the shape of the Earth.

Satellite altimetry has emerged as a cornerstone technology in Earth observation, enabling precise measurements of the planet's surface dynamics with unprecedented accuracy and detail. Among its numerous applications, one of the most fundamental is the determination of the geoid height (N), a critical parameter in geodesy and Earth sciences. The geoid, defined as the equipotential surface of the Earth's gravity field that best fits global mean sea level, serves as a reference surface for measuring elevations and understanding the Earth's gravity field.

The integration of the Broadview RADAR Altimeter Toolbox (BRAT) with data from the Sentinel-3 missions presents a promising avenue for advancing our capability to accurately

determine geoid height. Sentinel-3, part of the European Space Agency's Copernicus program, comprises a series of satellites equipped with advanced altimeters capable of measuring Sea Surface Height (SSH) with exceptional precision and coverage. When combined with BRAT, a powerful software suite specifically designed for processing altimetry data, these missions offer a robust framework for deriving geodetically significant parameters such as geoid height.

In recent years, satellite altimetry has been used in conjunction with other techniques, such as Satellite gravity measurements, to improve geoid determination [3]. The GRACE mission, for example, used satellite gravity measurements to provide information on the Earth's gravity field, which was then used to refine geoid models [2]. The GRACE mission demonstrated the importance of combining different techniques for improving geoid determination [2]. Satellite altimetry has played a crucial role in geoid determination, providing valuable information on the Earth's gravity field and its effect on sea level and ocean circulation [1]. The use of satellite altimetry in conjunction with other techniques, such as satellite gravity measurements, has

helped to refine geoid models and improve our understanding of the Earth's shape and its impact on various applications [3]. The geoid determined from satellite altimetry data can be used to correct for gravitational effects in remote sensing data, improving the accuracy of satellite altimetry. This is particularly important for oceanography, where satellite altimetry is used to measure ocean surface height and study oceanic circulation patterns [4].

II. LITERATURE REVIEW

Determination of Geoid Undulation (N) By Satellite Altimetry

Satellite Altimetry is one of the most recently developed methods of satellite geodesy (over 25 years old), which has led to important scientific results in geodesy, geophysics and oceanography. Substantial efforts have been made for about three decade to advance the stability, resolution and accuracy of the satellite altimetry observing system [5].

The quantity H (Figure 1), namely the separation between the mean sea surface and the geoid, means a disturbance or white noise to the geodesist, who models the geoid, and it constitutes the observation signal for the physical oceanographer in the study of ocean dynamics. On the other hand, the geophysicist can, from the large-scale analysis of H , derive valuable insight into the structure of the ocean floor and the tectonic features below it [6].

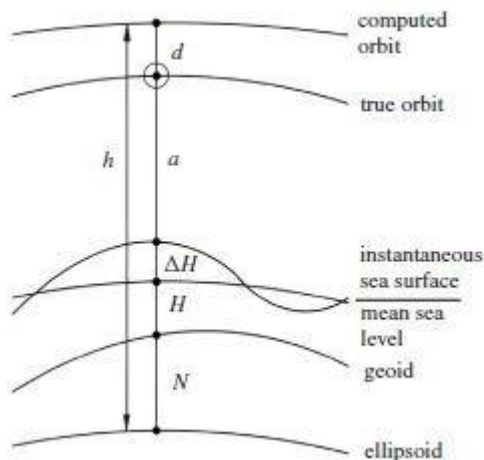


Fig. 1. Basic concept of satellite altimetry

Source: Nielsen *et al.*, [7].

The satellite is used as a moving platform for a sensor which transmits microwave pulses in the radar frequency domain to the ground and receives the return signals after reflection at the earth's surface. The altitude (a) of the satellite above the surface of the earth can be derived, as a first approximation, from the observed round travel time (t) of the radar signal as

$$a = c \frac{\Delta t}{2} \quad (1)$$

Where, c is the velocity of light.

This method is especially suited to the ocean surface because of the good reflective properties of water. A circular area with a diameter of a few kilometres, the so-called footprint is illuminated at the instantaneous sea surface, the size of which is related to the spatial resolution of the incoming microwave beam. According to Luca *et al.* [8], the emitted high frequency signal towards the Earth and reflected by the analyzed surface contains a vast range of information that can be used in various applications, the technique being an efficient method to determine the state of the ocean and seas and that of the natural conditions of the extended sea surfaces. These measurements refer to a mean instantaneous sea surface height which differs from the geoid height by the separation, H . The satellite altitude, h , above a global ellipsoid, can be derived from an orbit computation for a geocentric reference frame (Figures 1 and 2). The basic simplified equation of satellite geoid height is:

$$N = h - (H + \alpha) \quad (2)$$

Equation (2) is presented in detail as

$$N = h - (H + \Delta H + \alpha + d) \quad (3)$$

Where,

N = geoidal height

h = ellipsoidal height of satellite altimeter

H = SST (Sea Surface Topography)

ΔH = instantaneous tidal effects

α = altimeter measurements

d = total orbit errors.

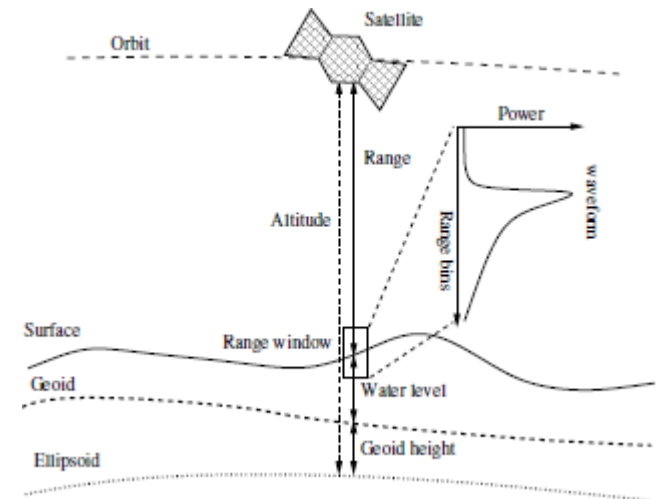


Fig. 2. Satellite Altimetry Techniques

Source: Nielsen *et al.*, [7].

The main significance of the satellite altimetry geoid determination is the possibility of scanning large ocean surfaces within a fairly short time period and determining a detailed representation of the sea surface with a high resolution in space and time. Initial tests with SKYLAB mission (1973-1974) produced accuracies of 1 to 2m geoid

heights. The new missions of the SEAS AT and GEOS produced improved precision of 3.5cm for height measurements. Current missions involve the ERS and TOPEX /POSEIDON missions with altimeter accuracies of better than 10cm. It must be mentioned here that the mean sea level (MSL) is taken to be the stationary sea surface freed from all time-dependent variations. The difference between this mean sea surface and the geoid is called the Sea Surface Topography (SST). The SST is caused by inhomogeneity in sea water caused by different ocean water salinities, large scale atmospheric pressure differences, strong currents, geostrophic winds, global temperature pattern changes, glacial melting, coastal pattern changes, river discharge and polar motion [9]. A satellite altimeter measures the range A from the satellite to the sea surface over large areas of the oceans. With the height H_S of the satellite above a reference ellipsoid being determined independently by precise orbit determination techniques, the height H_M of the sea surface above the reference ellipsoid is obtained as shown in Figure 3.

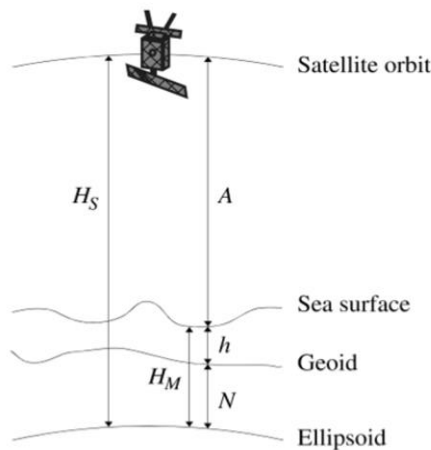


Fig. 3. Geometry of Satellite Altimetry

Source: (Seeber, 1993).

If the sea surface were only affected by the earth gravity force, it would be at rest and coincide with the geoid, the equipotential surface of the earth gravity field at mean sea level. However, because of oceanic currents the actual sea surface deviates from the geoid. The geoid may be described at any given point by the geoid undulation N , the height of the geoid above the reference ellipsoid, while the height of the sea surface above the geoid is known as the sea surface topography h . Thus, the sea surface height H_M is related to the sum of the geoid undulation N and the sea surface topography h by

$$H_M = N + h \quad (4)$$

III. METHODOLOGY

This study employed an experimental research design method. The data used in this research include: Satellite

Altimetry Data, Latitude, Longitude and Ellipsoidal Height. The primary data were obtained through field visits to the selected Towns peculiar to the study area. These include 17 (A001-A017) selected stations within the Towns covered by Awka and Environ (Isiagu, Nibo, Umuawulu, Nise, Amawbia, Amaenyi, Aguawka, Umuokpu, Amansea, Ifite-Awka, Okpuno, Isuaniocha, Mgbakwu, Urum, Amanuke, Achalla, and Ebenebe). The stations' Latitude, Longitude and Ellipsoidal Height were obtained using Ground Measurements from GNSS observations. The secondary datasets needed were obtained from the administrative boundary map of Anambra State which was obtained from the Department of Survey, Ministry of Lands, Surveys and Town planning, Anambra State, Nigeria. And Sentinel-3 data was obtained from Open Access Hub (copernicus.eu)

The entire data processing workflow was executed within the Broadview Radar Altimetry Toolbox (BRAT) GUI, a comprehensive tool adept at handling various radar altimetry data sources. Notably, it can seamlessly process data from missions such as ERS-1 & 2 (ESA), Topex/Poseidon (NASA/CNES), Geosat Follow-On (US Navy), Jason-1 (CNES/NASA), Envisat (ESA), Cryosat (ESA), Jason-2 (CNES/NASA/EUMETSAT/NOAA), and Sentinel-3 (ESA/EU).

The input data for this analysis comprised the Sentinel-3 SRAL Level 2 Water (WAT) Product and SRAL Level 2 Land (LAN) Product. The Sentinel-3 SRAL WAT Product provided critical information pertaining to water surfaces, including sea surface height (SSH), significant wave height (SWH), and wind speed over oceans and large water bodies. The data was structured in the Network Common Data Form (NetCDF) format.

Embedded within the standard measurements of the Sentinel-3 SRAL WAT Product are crucial parameters such as Sea Surface Height (SSH), Significant Wave Height (SWH), Wind Speed, Mean Dynamic Topography (MDT), Sea Level Anomaly (SLA), and Geophysical Corrections. These corrections are integral to account for atmospheric effects, tides, and instrumental errors in the raw altimetry data.

IV. RESULTS AND DISCUSSION

The determination of Geoid height (N) through satellite altimetry reveals a relatively confined range, with the lowest recorded height at 18.63m and the highest at 21.86m. The mean geoidal height of 20.75m serves as a central point, indicating a prevalent geoid height within this observed range. The accompanying standard deviation of 0.68m denotes a moderate degree of variability around the mean, suggesting discernible spatial fluctuations in geoid heights across the region.

The observed narrow range, exemplified by the minimum of 18.63m and maximum of 21.86m, implies a notably uniform geoid surface within the study area. The mean geoidal height

at 20.75m acts as a reference, representing the average elevation across the dataset. The standard deviation of 0.68m indicates the degree of deviation from this mean, underscoring a moderate level of spatial variation in geoid heights. It also implies that geoid heights can be obtained within the study area with accuracy 0.68m.

V. CONCLUSION

This study has yielded invaluable insights into the geodetic characteristics of Awka and Environs in Anambra State through the meticulous determination of the geoid heights of the study area. The utilization of satellite altimetry has enabled the determination of a confined range of Geoid heights of Awka and Environs and also extended it to the determination of Orthometric heights of the study area.

The accuracy and reliability of the determined geoid were assessed employing regression analysis, mean error, root mean square error, and standard deviation. The robust positive correlation, substantial explanatory power, and precision of the model, as indicated by various metrics, underscore its suitability for diverse applications, instilling confidence in its practical utility.

This study not only contributes a geodetic profile of Awka and Environs in Anambra State but accentuates the tangible applications and implications associated with understanding ellipsoidal height (h) and Orthometric height (H).

REFERENCES

1. Smith, W. H. F., and Sandwell, D. T. (1997). Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings. *Science*, 277(5334), 1956-1962.
2. Flechtner, F., Dahle, C., Gruber, C., König, R., Kusche, J., Mayer-Gürr, T., et al. (2017). AOD1B product description document for GOCE data release 6.0. GFZ Data Services.
3. Bos, M. S., and Tregoning, P. (2015). Geodetic Earth Observation with GRACE: Review and Future Prospects. *Remote Sensing of Environment*, 163, 117-129.
4. Wunsch, C., and Heimbach, P. (2013). Dynamical balance, the ocean and nonlinear geostrophy. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 371(1991), 20120363.
5. Guérou, A., Meyssignac, B., Prandi1, P., Ablain, M., Ribes, A. and François Bignalet-Cazalet, F. (2023). Current Observed Global Mean Sea Level Rise and Acceleration Estimated from Satellite Altimetry and the Associated Measurement Uncertainty. *Ocean Science*, 19, 431–451.
6. Seeber, G.: Satellite Geodesy (1993). Foundations, Methods and Applications. Walter der Gruyter, Berlin NY, 1st Ed.
7. Nielsen, K., Stenseng, L., Andersen, O. B. and Knudsen, P. (2017). The Performance and Potentials of the CryoSat-2 SAR and SARIn Modes for Lake Level Estimation. *Water*, 9(374).
8. Luca, E., Bandoc, G. and Degeratu, M. (2023). Comparative Analysis of Significant Wave Height Between Satellite Altimetry Data and SWAN Model Simulations in the Black Sea Basin. *IOP Conference Series: Earth and Environmental Science* 1185 012022.
9. Schrama, C. J. O. (1996). Satellite Altimetry, Ocean Dynamics and the Marine Geoid. Inter summer.